Army Research Laboratory

Detecting Human Activity using Acoustic, Seismic, Accelerometer, Video, and E-field Sensors

by Sarah H. Walker and Geoffrey H. Goldman

ARL-TR-5729 **September 2011**

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Army Research Laboratory
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14. ABSTRACT

Situational awareness plays a critical role in the decision-making process for today's Soldier. It is important for a Soldier to know from what direction an enemy is approaching. Obtaining and using information gathered from low-cost sensors like acoustic, seismic, e-field, imagery, accelerometers, and others can provide a means to monitor human-based activity. This report investigates the feasibility of using an array of low-cost sensors for determining the patterns and activities of people that occur in a typical breakroom during lunch time. The test results show that it is possible to detect and interpret activity in urban settings, such as in buildings, with low-cost sensors and, thus, show promise for enhancing the situational awareness of today's Soldier.

15. SUBJECT TERMS

Data collection, sensors, human activity, building

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1. Introduction

Detecting people is an essential tool for protecting today's Solider. Recent development of low-cost sensors like acoustic, seismic, e-field, imagery, and accelerometers has opened up a new field of research for understanding human-based activities. Many researchers are creating sensor systems that detect human presence and recent human activity, passive acoustic sensing of walking, and multimodal sensor signatures to classify walking/jogging (*1*, *2*, *3*). To be able to distinguish certain human motion patterns also takes on an important role in comprehending and observing human activity.

2. Experiment

In this experiment, acoustic, seismic, video, accelerometer, and e-field sensors were used to monitor human activity in a lab bay with a high level of activity. Figure 1 shows the layout of the breakroom where the sensors were positioned. Two video cameras were placed in a position to capture the human activity and provided recorded ground truth. In addition, two students monitored the breakroom and manually recorded the time and type of activity that occurred.

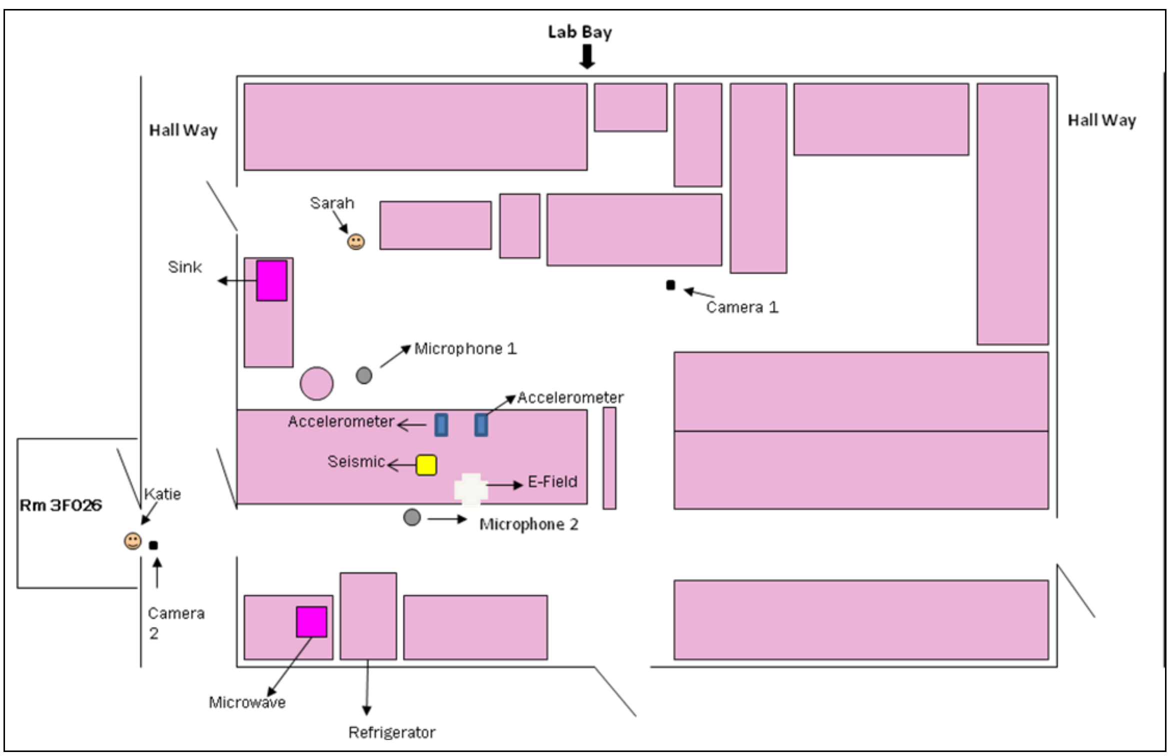


Figure 1. Diagram of the lab bay with the location of sensors.

The sensors recorded human activity over the span of 1 h; data were recorded using the Wavebook data acquisition system shown in figure 2 and then processed using MATLAB.

Figure 2. Wavebook data acquisition system. Wavebook is a device that offers many channel waveform acquisition and analysis for portable laboratory applications.

The Wavebook can record up to eight channels of data at a sample rate up to 100 KHz. Table 1 shows the sensors that were measured on each channel of the Wavebook at a sample rate of 12 kHz.

Table 1. Channel numbers for the sensors.

Channel number	**Sensor**
1	Acoustic: Microphone 1
2	Acoustic: Microphone 2
3	Vertical Seismic
4	Seismic
5	Accelerometer
6	Accelerometer
7	E-field

A description of the data files recorded is shown in table 2. The table describes the file names, a description of the data, the file size, and the file type. The data recorded on the Wavebook were displayed using software written in MATLAB, version R2010b. Appendix A shows the code used to display the data. Two video cameras also recorded the activity in the lab bay. In addition, two workers sitting at the locations of the videos cameras kept a log of the activity. The logs are shown in appendix B.

Table 2. Description of the data files collected during the experiment.

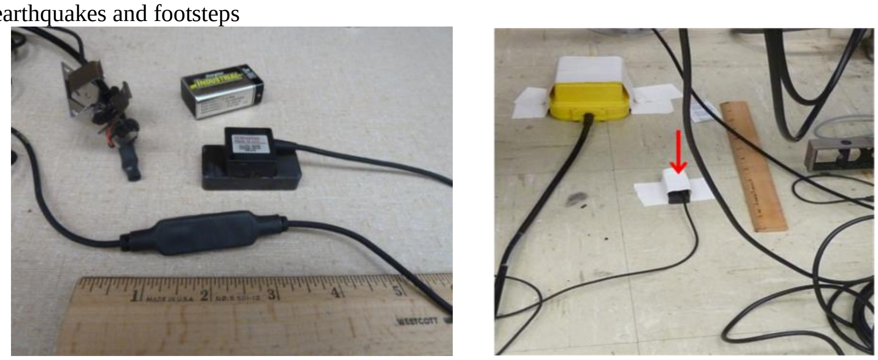
File Name	Description	Size	Type
Video 1: 106_0050	Video 1 was placed in the breakroom that was positioned to capture activity around microphone 1, the sink, and the trash can.	1,267,483 KB	QuickTime Movie
Video 2: 104_0048	Video 2 was placed in Room 3F026 perpendicular to the hallway. It was positioned so that the sensor could capture activity of people walking by in the hallway, people going to the microwave, or to the refrigerator to get food.	1,143,169 KB	QuickTime Movie
Data File: LabEc056.bin	The data recorded through the four sensors was stored as a BIN file.	684,769 KB	BIN File

2.1 Sensors

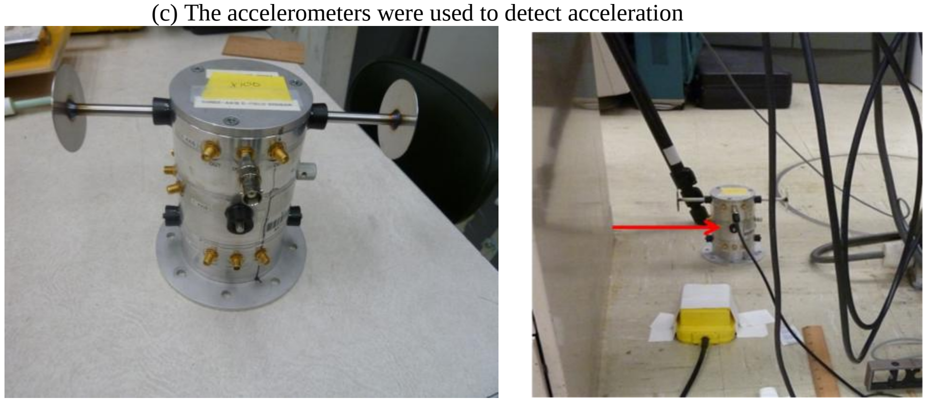
Four low cost non-line-of-sight sensors (NLOS) and two video cameras were used to monitor activity in the lab bay. Figure 4 shows several of the sensors used in the experiment. Figure 4a shows the seismic sensor that was used to capture data involving the movements on the ground, such as a person walking into the breakroom to wash their dishes in the sink. Figure 4b shows one of the two acoustics sensors and a wind screen, which was used to protect the microphone from damage. Figure 4c shows an accelerometer that is taped to the floor. Figure 4d shows an E-field sensor that is placed on the floor, and figure 4e shows one of the video cameras.

(a) The seismic sensor measures movement of the ground, as well as seismic waves produced by earthquakes and footsteps

(b) Acoustic sensor: microphone used to amplify and transmit sound.



(c) The accelerometers were used to detect acceleration



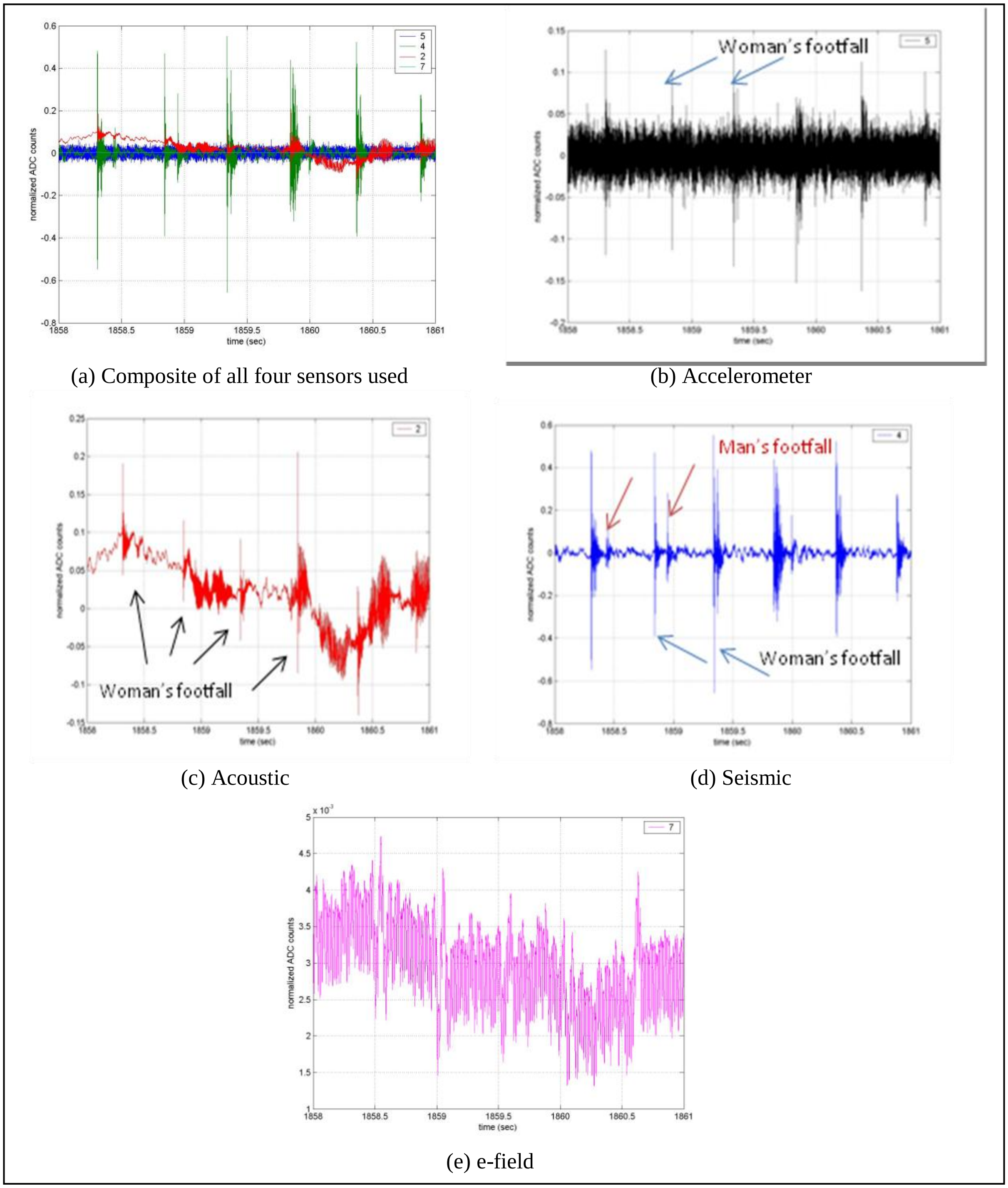
(d) E-Field sensor

(e) Imagery sensor

Figure 4. Displayed above were the sensors used in the experiment

3. Results

Outputs from the sensors were plotted using MATLAB and visually analyzed. Figure 5 shows the sensor output of two people walking together; one was a man wearing tennis shoes, and the other was a woman wearing high heels. Figure 5a shows the output of all four NLOS sensors together, and figures 5b-e show the output of the individual sensors with the amplitudes adjusted to better see the signals. As we look in the acoustic signal, we can see the scuffing of the woman's heel. In the seismic signal, there is a clear view of the woman's footfall and the man's footfall. The woman's footstep has more of a pronounce image due to the sound of her heel hitting the floor, rather than the man's footstep with the rubber of his tennis shoes hitting the floor. The E-field output has an approximate 0.25 s delay relative to the location of the footfalls seen in the seismic, accelerometer, and acoustic data. This may be due to a static change being generated when the legs crossed during a gate.



(a) Composite of all four sensors used

(b) Accelerometer

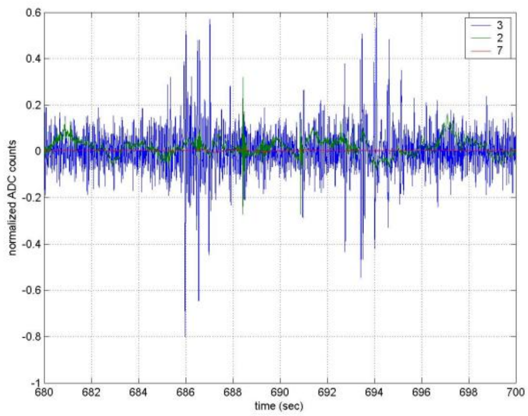
(c) Acoustic

(d) Seismic

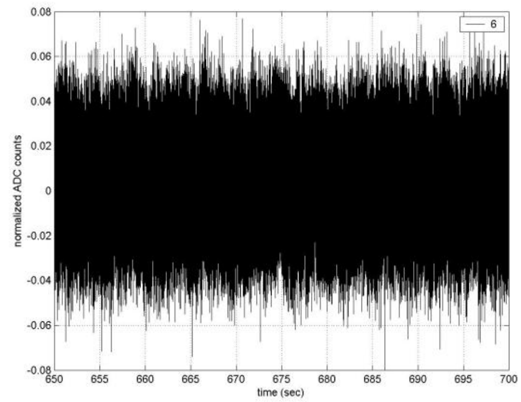
(e) e-field

Figure 5. Activity: Multisensor data for two people walking. One is walking with high heels the other is walking with tennis shoes.

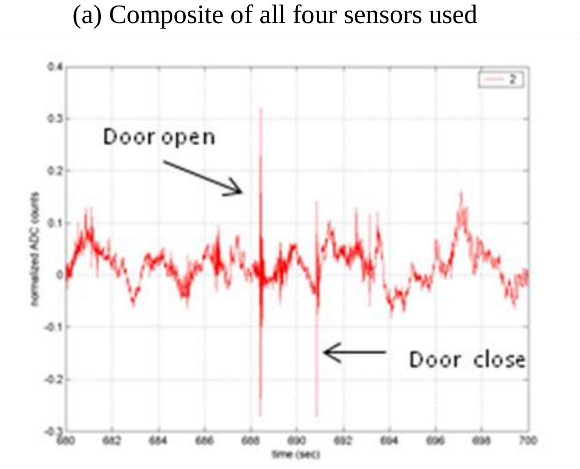
Figure 6 show the sensor outputs for a refrigerator door opening and then closing 3 s later. Figure 6a shows the output of all four NLOS sensors together, and figures 6b-e show the output of the individual sensors. In figure 6c, we can clearly observe when the refrigerator door is opened and closed based upon the location of the acoustic transient signal. The output of the other sensors is more complex.



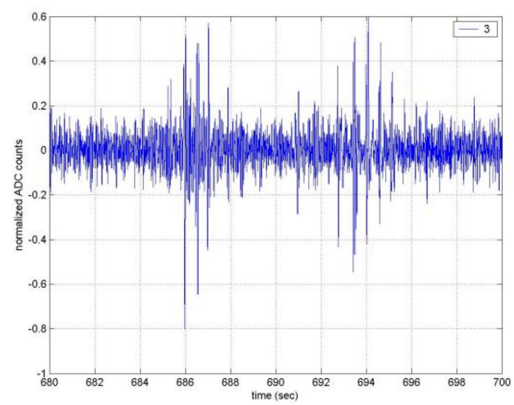
(a) Composite of all four sensors used



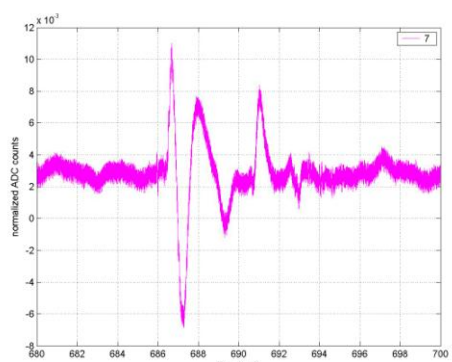
(b) Accelerometer



(c) Acoustic



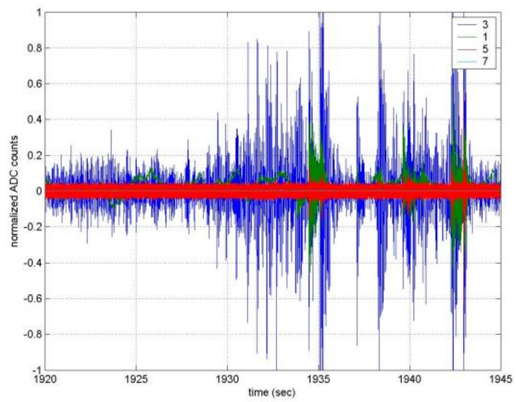
(d) Seismic



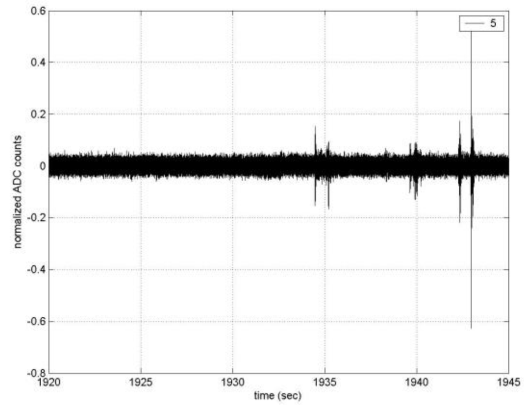
(e) E-Field

Figure 6. Activity: Opening and closing a refrigerator door.

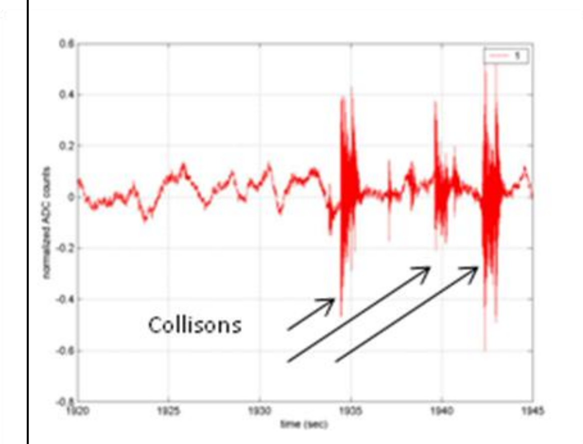
Figure 7 shows a span of 25 s where a person rolled a cart through the breakroom, shown with the four sensors. Figure 7a shows the output of all four NLOS sensors together, and figures 7 b-e show the output of the individual sensors. Large transients can be seen in the acoustic signal in figure 7c when in bumped-into structures in the lab bay.



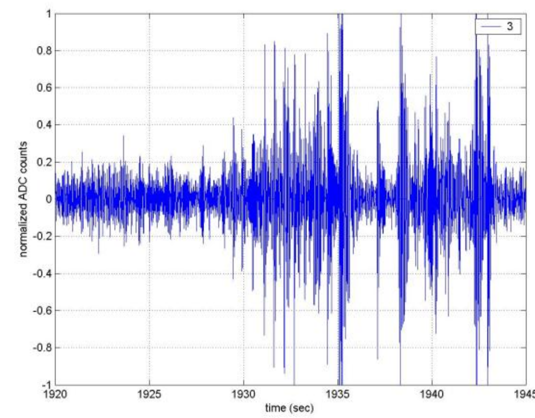
(a) Composite of all four sensors used



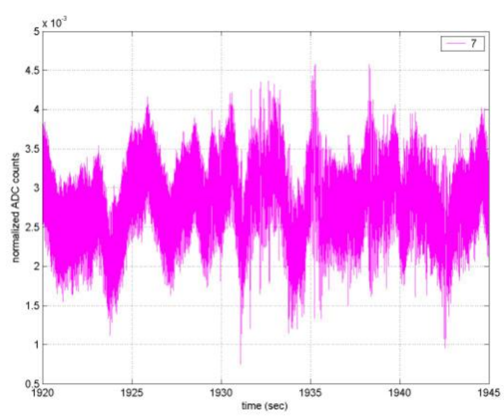
(b) Accelerometer



(c) Acoustic



(d) Seismic



(e) E-Field

Figure 7. Activity: Person rolling a cart through the break room.

4. Conclusions

In this project, many of the activities, such as making lunch and getting coffee, were recognized using the temporal characteristics of the displayed data, such as in figure 6a-e, which captured the human activity of opening and closing a refrigerator door. Looking through the data, men walking could be discriminated from a woman walking due to the amplitude and frequency of the acoustic, seismic, and accelerometer data. These inexpensive sensors provide a means for monitoring human activity and can provide better situational awareness for today's Solider.

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Appendix A. Code for Displaying Data Through MATLAB

```
% routine to load Wavebook *.bin data

% inputs: ..............................................
%   f_name ...    Input filename to load
% outputs: .............................................
% abcd .......... the NumScans (column) by numChannels (rows) data array
acquired by the wavebook
% GainValue ..... corresponds to the voltage setting for that channel 10V is
2, 5V is 1, etc.
% M_ ............ the slope in the Mx+B line formula
% B_ ............ the dc offset in the Mx+B formula
% numChannels ... The number of channels acquiring data
% NumScans ...... The number of data points acquired for each channel
% preFreq ....... The sample rate the pre trigger data was acquired at
% postFreq ...... The sample rate the post trigger data was sampled at
% PreCount ...... The number of points acquired in the pre trigger sampling
% LABEL ......... A string array containing the label assigned each channel
% UNITS ......... A string array containing the units assigned each channel

% load data file by displaying files in data directory with dir;
% copy filename root and paste it into function call:
%     [abcd, GainValue, M_, B_, numChannels, NumScans, preFreq, postFreq,
PreCount, LABEL, UNITS] = wvbkldfn('filenameroot');
% time axis is created with:  t=(0:NumScans-1)/postFreq;
% data is in a NumScans by numChannels array
% example, plot array column 1 with:      plot(t,abcd(1,:))

function [abcd, GainValue, M_, B_, numChannels, NumScans, preFreq, postFreq,
PreCount, LABEL, UNITS] = ...
    wavebook_read_data(f_name,Nstart,Ntotal);

fid=fopen([f_name,'.dsc'],'r');

fseek(fid,0,'bof');
numChannels=fread(fid,1,'int16');
NumScans=fread(fid,1,'int32');
DigInputCh=fread(fid,1,'int32');
preFreq=fread(fid,1,'float32');
postFreq=fread(fid,1,'float32');
PreCount=fread(fid,1,'int32');
Packed=fread(fid,1,'int32');

for nn=1:numChannels
    GainValue(nn)=fread(fid,1,'float32');
    M_(nn)=fread(fid,1,'float32');
    B_(nn)=fread(fid,1,'float32');
    fread(fid,1,'float32');     %read bipolar flag (not correct value ?)
    uniadder(nn) = fread(fid,1,'float32');     %read uniadder, should be zero
for all bipolar acquisition
    LABEL(nn,1:9)=char(fread(fid,9,'uchar'))';
    UNITS(nn,1:9)=char(fread(fid,9,'uchar'))';
```

```
      if(1)
            disp(['Column ',num2str(nn),'      ', LABEL(nn,1:9), '      Volts
= ', num2str(GainValue(nn)/5), ...
                        '      Mult = ', num2str(M_(nn)), ...
                        '      Offset = ', num2str(B_(nn)), '      Units = ',
num2str(UNITS(nn,1:9))])
      end
end
fclose(fid);
disp(LABEL)

fid=fopen([f_name,'.bin'],'r');
if preFreq ~= postFreq & PreCount ~= 0, disp('pre and post trigger samples
not equal'), return, end
% abcd = fread(fid,[numChannels NumScans],'int16')';

stat=fseek(fid,(Nstart*numChannels*2),-1);
abcd = fread(fid,[numChannels Ntotal],'int16');

 %  abcd = fread(fid,[2 NumScans],'int16')';


if (Ntotal>0)
for nn=1:numChannels
    abcd(nn,:) =
((abcd(nn,:)*(5.0/GainValue(nn))/32768)+uniadder(nn))*M_(nn)+B_(nn);
end
end

%eval([f_name,' = abcd;']);

list=['Number of Channels = numChannels       ' ;...
            'Number of scans = NumScans             ' ;...
            'Digital input channel y/n = DigInputCh ' ;...
            'Pre trig sps = preFreq                 ' ;...
            'Post trig sps = postFreq               ' ;...
            'pre trig sample count = PreCount       ' ;...
            'Packed data y/n = Packed               ' ;...
            'Gain value (n channels) = GainValue    ' ;...
            'Unit multiplier (n ch) =  M_           ' ;...
            'Unit offset (n ch) = B_                ' ;...
            'uniadder (n ch) = uniadder             ' ;...
            'Channel label (n ch) = LABEL           ' ;...
            'Channel units (n ch) = UNITS           '];

if(1)
      disp([list(1,1:39), ' ----> ', num2str(numChannels)])
      disp([list(2,1:39), ' ----> ', num2str(NumScans)])
      if(PreCount ~= 0), disp([list(4,1:39), 'in KHz ----> ',
num2str(preFreq/1000)]), end
      disp([list(5,1:39), 'inKHz ----> ', num2str(postFreq/1000)])
      disp([list(6,1:39), ' ----> ', num2str(PreCount)])
      if(PreCount ~= 0), disp(['pre trigger time in seconds ----> ',
num2str(PreCount/preFreq)]), end
      disp(['post trigger time in seconds ----> ', num2str((NumScans-
PreCount)/postFreq)])
end
```

```
fclose(fid);

%clear nn fid ans abcd


% code to read one channel of a wavebook file
% written by Jeff Goldman, June 2011
% modified from Chris Reiff's code

%close all

clear all

plot_raw_data_flag=1;  % 0,1
plot_dec_data_flag=0;  % 0,1

single_chan_flag=0;  % 1=plot one channel, 0=plot all channels
channel_num=2;  % 1-7

R=2;  % decimate data by R

time_start=1600;  %  seconds
time_end= 2000; % seconds
filename_root='C:\Documents and
Settings\Administrator\Desktop\Sarah.W\LabEc056';

if (single_chan_flag==1)
    K=10;  % break data up into smaller intervals for memory management
    BB=K;
else
    K=1;
    BB=1;
end

[x, GainValue, M_, B_, numChannels, NumScans, preFreq, postFreq, PreCount,
LABEL, UNITS] = ...
    wavebook_read_data(filename_root,0,0);

Nstart= BB*round(((time_start)*preFreq)/BB);
Ntotal= BB*round(((time_end-time_start)*preFreq)/BB);

time_start=Nstart/preFreq;
time_tot=  Ntotal/preFreq;

if (single_chan_flag==1)
    data=zeros(1,Ntotal);
end

for k=1:K

    Nstartsub=round(Nstart + Ntotal*(k-1)/K);  % for seek command
    Nstartsub_index=round(Ntotal*(k-1)/K);  % for indexing data array

    Nendsub=round(Nstart + Ntotal*(k)/K);
    Nendsub_index=round(Ntotal*(k)/K);
```

```
    Ntotalsub=Nendsub-Nstartsub;

    if (single_chan_flag==1)
        [x, GainValue, M_, B_, numChannels, NumScans, preFreq, postFreq,
PreCount, LABEL, UNITS] = ...
            wavebook_read_data(filename_root,Nstartsub,Ntotalsub);
        data(1,(Nstartsub_index+1):Nendsub_index)=x(channel_num,:);
        [columns,N]=size(x);
        clear x;
    else
        [data, GainValue, M_, B_, numChannels, NumScans, preFreq, postFreq,
PreCount, LABEL, UNITS] = ...
            wavebook_read_data(filename_root,Nstartsub,Ntotalsub);
        [columns,N]=size(data);
    end
end   % for k

if (single_chan_flag==1);  % 1=plot one channel

    if (plot_raw_data_flag)
        time_array=(Nstart:(Nstart+Ntotal -1))/preFreq;
        figure
        plot(time_array,data)
        grid on
        xlabel('time (sec)')
        ylabel('normalized ADC counts')
        title(['channel =',num2str(channel_num)])
    end


    if (plot_dec_data_flag)
        dataR=decimate(data,R);
        timeR_array=R*(round(Nstart/R):(round(Nstart/R+Ntotal/R)-1))/preFreq;

        figure
        plot(timeR_array,dataR)
        grid on
        xlabel('time (sec)  - decimated')
        ylabel('normalized ADC counts')
%        title(['channel =',num2str(channel_num)])
    end
else

    if (plot_raw_data_flag)
        time_array=(Nstart:(Nstart+Ntotal -1))/preFreq;
        figure
        plot(time_array,data([6],:),'r')
        legend(num2str(1:(columns-1),'%1d')')
        legend('6')
        grid on
        xlabel('time (sec)')
        ylabel('normalized ADC counts')
    end

    if (plot_dec_data_flag)
        dataR=zeros(columns,ceil(Ntotal/R));
        for k=1:columns
```

```
            dataR(k,:)=decimate(data(k,:),R);
        end
        timeR_array=R*(round(Nstart/R):(round(Nstart/R+Ntotal/R)-1))/preFreq;

        figure
        plot(timeR_array,dataR)
        grid on
        xlabel('time (sec)  - decimated')
        ylabel('normalized ADC counts')
        legend(num2str(1:columns,'%1d')')
    end
end
```

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Appendix B. Log Files

Camera 1-view point: sink and trash can   Date: 6/16/11

Time	Description
11:20:00	Start Experiment
11:21:00	Weight dropped
11:21:15	Weight dropped
11:21:26	Weight dropped
11:24:00	Walked in
11:24:10	Dropped change in coffee can
11:24:12	Coffee
11:24:30	Walked out
11:24:45	Microwave opened
11:24:50	Microwave closed
11:25:00	Microwave opened
11:25:05	Microwave closed
11:26:35	Walked in
11:26:40	Talking
11:28:35	Talking end
11:29:10	Walked by
11:30:00	Walked in
11:30:10	Refrigerator open
11:30:15	Refrigerator close
11:30:45	Shake of dressing bottle
11:30:55	Refrigerator open
11:30:59	Refrigerator close
11:31:25	Counter noise
11:31:35	Microwave open
11:31:45	Water on
11:31:55	Talking
11:32:00	Microwave close
11:32:15	Water off
11:32:20	Water on/off
11:32:25	Paper towels
11:33:35	Microwave running
11:34:35	Microwave off
11:34:45	Microwave open
11:34:55	Microwave close
11:38:30	Water on
11:39:05	Water off
11:39:25	Walked out
11:40:00	Coffee
11:40:40	Noise of trash can

Time	Description
11:41:05	Paper towels
11:43:15	Walked by
11:46:50	Black box
11:47:20	Talking
11:47:50	Close box
11:48:30	Closet open
11:48:50	Closet close
11:50:20	Walked by with heels
11:50:45	Walked by
11:51:30	Cart rolling by
11:51:50	Cart hits trash can
11:52:25	Burp
11:52:40	Talking
11:52:43	Someone gets some ice
11:53:00	Open soda can
11:56:00	2 people walk by
11:56:15	2 people walk by
12:00:20	Walk by
12:00:40	Noise
12:01:40	Walk by
12:02:45	Talking
12:03:25	Walk by/Talking
12:03:45	Talking
12:05:00	Walk by
12:05:10	Coffee
12:05:20	Walk by
12:05:30	Refrigerator open
12:05:40	Refrigerator close
12:10:00	Talking
12:10:40	Walk by
12:14:45	Walk by
12:17:25	Walk by
12:17:35	Talking
12:17:40	Water on
12:18:05	Towels
12:18:16	Towels
12:18:28	Walked out
12:18:55	Walked by
12:20:00	End Experiment

Camera 2- view point: microwave and refrigerator

Time	Description
11:20:10	Start Experiment
11:20:35	Dropped Weight
11:20:47	Dropped Weight
11:20:57	Dropped Weight
11:21:05	Person Walking by ←
11:21:20	Person Walking in/out of room↑
11:22: 30	Person Walking by ←
11: 22:50	Person Walking out of room ↓
11:23:05	Refrigerator Open
11:23:07	Person Walking into room ↑
11:23:08	Refrigerator Closed
11:23:11	Microwave Open then Closed
11:23:12	Microwave turned on
11:23:30	Person Walking out of room ↓
11:23:32	Microwave Open then Closed
11:23:37	Person Walking into room ↑
11:25:02	2 People Walking out of room ↓
11:26: 25	Person Walking in/out room ↑
11:26:40	Person Walking by ←
11:26:41	Person Walking by →
11:27:20	Person Walking by ←
11:27:30	Person Walking by →
11:28:20	2 People Walking into room ↑
11:28:35	Person Walking by →
11:28:45	Person Walking in/out room ↓ Talking
11:29:25	Person Walking into room ↓
11:29:30	Refrigerator Open *stuff moved
11:29:45	Person Opening lid of container
11:30:10	Person Closing lid of container
11:30:17	Person Shaking container
11:30:30	Refrigerator Open
11:30:32	Refrigerator Close
11:30:37	Person Walking into room ↑
11:30:55	Person Walking into room ↑
11:31:05	Microwave Open
11:31:08	Person Walking in Talking ↑
11:31:11	Person Walking out ↓
11:31:30	Microwave Close
11:31:35	Person Talking by Microphones
11:32:05	Microwave On Person Walking ↑

Time	Description
11:32:06	Person Walking out of room ↓
11:33:15	Person Walking into room ↑
11:33:17	Microwave off and Open
11:33:18	Person Opening a container
11:33:23	Microwave Close
11:33:27	Person Walking out of room ↓
11:35:20	Person Walking by →
11:36:45	Person Walking in/out ↓
11:36:51	Sink turned On
11:37:10	Person Walking by →
11:37:37	Sink turned Off
11:37:40	Person Walking by ←
11:37:58	Person Walking into room ↑
11:38:01	Person Walking by →
11:39:45	Person Walking by →
11:40:18	Person Walking by ←
11:42:30	2 People Walking by ←
11:42:45	Person Walking into room ↑
11:42:56	Person Walking out of room ↓
11:43:05	Person Walking by ←
11:43:08	Person Walking by ←
11:45:13	Person Walking by ←
11:46:15	Person Walking out of room ↓
11:46:25	Person Grabs case off of shelf
11:46:31	Person Drops case onto floor
11:46:35	People Talking while inside room
11:47:10	Person disassembles case
11:47:20	Person Closes case
11:47:51	Person puts case back on shelf
11:48:01	Person opens metal cabinets
11:48:20	Person Closes cabinets
11:48:23	Person Walking into room ↑
11:49:32	Person Walking by →
11:49:40	2 People walk in/out of room ↓
11:50:25	Person Walking in/out of room ↑
11:51:05	Person rolls metal cart into room ↓
11:51:15	..bangs metal cart into trash can
11:51:30	Person leaves room with cart
11:51:35	Person Walks by w/ metal cart →
11:51:52	2 People Walk by
11:52:03	2 People Walk out of room ↓

Time	Description
11:52:12	Fridge Open *Talking occurring
11:52:20	Fridge Close
11:52:31	Soda can Open
11:52:45	2 People Walking in/out ↓
11:52:46	Person throws can in trash can
11:55:40	Person Walks by *wearing heels
11:56:50	Sink On
11:56:54	Sink off
11:57:12	2 People Walking into room ↓
11:57:45	2 People walking back in ↑
11:58:50	Person Walking by Talking
12:00:10	*People Talking by microphones
12:01:12	Person Waling out ↓
12:03:07	Person Walking In ↑
12:03:35	Person Walking by ←
12:04:27	Person Walking by →
12:04:29	Person Walking in/out ↓
12:04:35	Person Walking by ←
12:04:38	Person Walking by →
12:04:41	Person Walking into room ↑
12:04:43	Microwave Open/Close
12:04:50	Person Walking into room ↑
12:07:20	Person Walking by →
12:08:25	Person Walking by →
12:08:37	Person Walking by →
12:09:15	2 People Walking by *stop by door
12:10:15	Person Walking in/out of room ↓
12:10:16	Person Walking by ←
12:10:30	Person Walking by →
12:11:08	Person Walking by →
12:11:09	Person Walking by ←
12:13:55	Person Walking by →
12:14:20	Person Walking in/out of room
12:15:03	Person Walking into room ↑
12:15:05	Person Walking by → *in heels
12:15:10	Person Walking out of room ↑
12:15:45	Person Walking by →*man with metal souls on shoes
12:16:42	Person Walking by →
12:17:02	Person Walking into room ↓
12:17:15	Sink turned On
12:17:35	Sink turned Off
12:17:37	Person Drying hands
12:18:05	Person Walking by →
12:18:25	Person Walking by ←
12:18:45	Person Walking in/out ↑
12:19:25	Person walks by ←
12:20:00	End experiment

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TOTAL: 5 (1 ELEC, 4 HCS)